STRATIGRAPHY OF UPPERMOST CRETACEOUS AND LOWER TERTIARY ROCKS OF THE DENVER BASIN

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ABSTRACT

Uppermost Cretaceous and Lower Tertiary rocks total about 3,000 ft (915 m) in thickness in the Denver basin. Sandstone, shale, and coal of the Upper Cretaceous Laramie Formation are unconformably overlain by conglomerate and sandstone of the Upper Cretaceous Arapahoe Formation. The overlying Denver Formation, which includes the Cretaceous-Paleocene boundary, is composed of fine-to coarse-grained andesitic sedimentary rocks and some coarse arkosic beds. It includes interbedded carbonaceous shales and lignites throughout most of the basin. A mappable contact separates the Denver from the overlying Dawson Arkose. The lower member of the Dawson, of late Paleocene age, is lenticular and is composed mainly of fine to coarse arkoses with some andesitic sedimentary rocks. It may be equivalent to the Green Mountain Conglomerate (Paleocene), which is composed of rocks with similar lithologies. The main body of the Dawson, composed mostly of coarse arkose and conglomerate, is of Eocene age and overlies a distinctive thick paleosol throughout most of the basin.

INTRODUCTION

The term Denver basin, as used in this paper, refers to the area south of Greeley, Colorado, but the emphasis here will be on the more central part, which includes all of the areal extent of the Dawson Arkose (Fig. 1). Rocks described here include all of the coal deposits of the basin and are of continental origin. They overlie the Fox Hills Sandstone of Late Cretaceous age and of marine origin. Aggregate thickness is about 3,000 ft (915 m).

Over the past century, stratigraphic nomenclature applied to these rocks has varied from geologist to geologist and, in fact, from one locality to another as described by a given geologist (Fig. 2). Most of this is a result of (1) the limited areal extent of the individual studies, (2) the complications of faulting and thick Quaternary cover along the west side of the basin, where most studies have been made, and (3) facies changes. Only Reichert (1954, 1956) and the present author have undertaken basinwide studies on the bulk of these rocks. Of the authors listed on Figure 2, only in the present author's work have subsurface data been used extensively in stratigraphic interpretations.

LARAMIE FORMATION

The Laramie Formation of Late Cretaceous age consists of two members: a lower member of light yellowish-gray to white, relatively clean medium-grained sandstone, and an upper member of shale and claystone with a few thin beds of calcareous sandstone and subbituminous coal beds. Some of the best exposures are in the Corral Bluffs area, east of Colorado Springs (Soister, 1968b). Here the lower member is about 125-150 ft (38-46 m), contains *Ophiomorpha* (burrows), and is believed to have originated mostly as a beach sand. In the same area, the upper member is about 225 ft (69 m) thick, but in other parts of the basin may be as much as 400 ft (122 m) thick. There are generally about three coal beds in the upper member, each averaging about 1-5 ft (0.3-1.5 m) in thickness, but in some places a coal bed may be as much as 10 ft (3 m) or more in thickness. The lower or sandstone member of the Laramie locally contains lenses or lenticular beds of coal.

Early reports on the Laramie Formation designated the lower member, as used in this paper, the "A" and "B" sandstones, and commonly described them as forming "a single continuous outcrop" with the underlying Fox Hills Sandstone (Eldridge, *in* Emmons, Cross, and Eldridge, 1896, p. 73). The Fox Hills Sandstone can generally be distinguished from the Laramie's sandstone beds by its finer grain size, greater amount of ferruginous material, higher mica content, and marine fossils. However, it is common practice, especially in subsurface work, to map the lower member of the Laramie with the Fox Hills Sandstone; together they comprise one of the principal aquifers of the Denver basin (Romero and Hampton, 1972).

ARAPAHOE FORMATION

The Arapahoe Formation of Late Cretaceous age (named for Arapahoe County, Colorado) was first described from exposures in sections 6, 7, 18, 19, and 20, T7S, R68W, "where it has its greatest and most typical development" (Eldridge, 1888, p. 97); Eldridge's description of the Arapahoe is as follows:

> "It is composed of a basal member of conglomerate, or gritty sandstone, according to its distance from the foothills, with an overlying zone of gray, argillaceous or arenaceous shales, containing lenticular masses of hard, quartzose sandstone, with an occasional ironstone; where, confined between under- and over-lying groups, it has a thickness varying between 600 and 1,200 feet.
>
> The conglomerate at its base has a thickness, over the greater portion of the field, of about 200 feet, though this may become the bulk of

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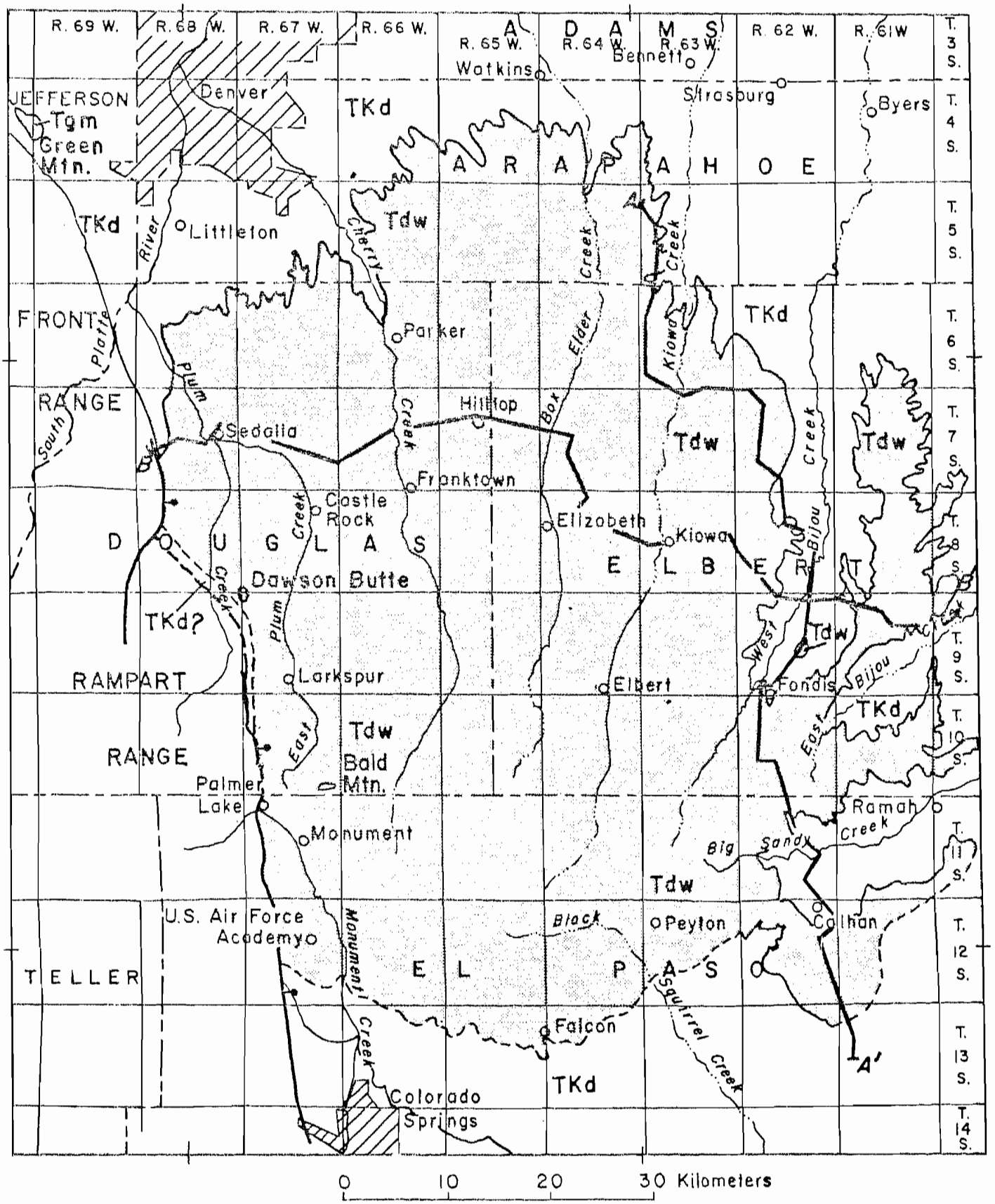

Fig. 1—Contact of the Denver Formation (TKd) and Dawson Arkose (Tdw) in the Denver basin, dashed where concealed over large areas. Arapahoe Formation mapped with Denver. A-A' and B-B' are lines of cross-sections of Figure 3. Post-Dawson rocks not shown.

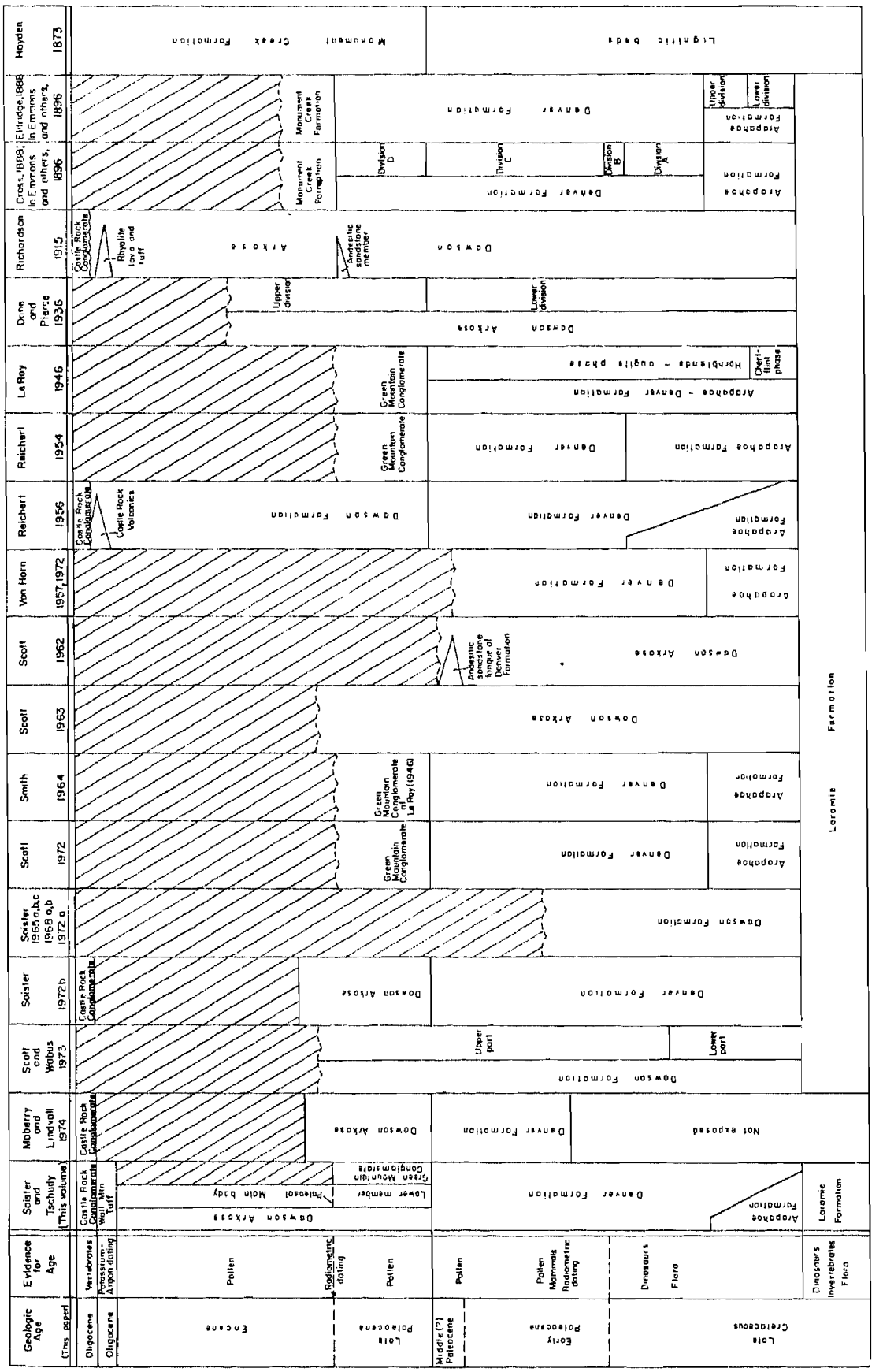

Fig. 2—Stratigraphic nomenclature of uppermost Cretaceous and lower Tertiary rocks, Denver basin, Colorado.

the formation, as in its type locality, or may decrease to the merest edge, as at its northern limit along the Platte River near Brighton."

Although the Arapahoe was originally described as having an uppermost zone of shales, the name has now become synonymous with the originally described "basal member" of quartzose and arkosic sandstone and conglomerate. This interval of coarse clastic rocks is important for its ground-water supplies.

The conglomerate also includes pebbles and small cobbles of limestone and other sedimentary rock types derived from Paleozoic and Mesozoic formations. On the surface it can be traced in intermittent outcrops along the basin edge from the Green Mountain area to about 7 km south of Dawson Butte. Some easily accessible exposures are in NW¼ sec. 6, T7S, R68W, SW¼ sec. 1, T9S, R68W, and near CS½ sec. 30, T9S, R67W. From near this last locality south to T13S, R67W, the Arapahoe is below the surface owing to thick Quaternary deposits and to faults that place the higher Dawson Arkose against older rocks. In the Colorado Springs area, Finlay (1916, p. 9) described siliceous (quartzose) sandstone with rounded quartz and chert pebbles; these rock types are common in the formation. The present author found these same type beds as far east as T13S, R64W; farther east, thick Quaternary alluvium and eolian sands cover these rocks. In the southwest and southern parts of the basin, the Arapahoe is not a distinctive mappable unit and has been mapped with the overlying Denver Formation. On the east side of the Denver basin, lenticular arkosic sandstone and granite pebble conglomerate beds a few m thick are probable correlatives of the Arapahoe, but are included in the Denver Formation.

In the subsurface, the Arapahoe can be differentiated from the underlying Laramie Formation by the appearance of sandstone or conglomerate above the Laramie shales. Sandstone and/or conglomerate at this interval varies in thickness from a few meters to more than a hundred meters, increasing to the west toward the mountain sources. In most drill-hole logs, the interbedding of sandstone with finer-grained beds upward into the Denver Formation makes it difficult or impossible to pick a contact between these two formations. From a drill hole study north of Golden, Hurr (1976, p. 44-45) described the Arapahoe as consisting of about 270 ft (82 m) of "lenticular sand bodies interbedded with clay."

DENVER FORMATION

The Denver Formation of Late Cretaceous and Paleocene age was named after the city of Denver because its "beds form the surface about the city" (Cross, 1888, p. 119). The formation was said by Cross (1888, p. 119, 122) to be unconformably underlain and overlain by, respectively, the Arapahoe Formation and "Monument Creek beds" (Dawson Arkose of this report).

One restriction put on the extent of the Denver Formation by Cross (1888, p. 123; Emmon, Cross, and Eldridge, 1896, p. 194-196) and by Eldridge (Emmons, Cross, and Eldridge, 1896, p. 323-326, p. 373-375, plates 2, 3, and 4) is invalid. Their description of beds in the areas just northeast and east of the city of Denver, and of the Scranton coal and the coal bed on the east bank of Coal Creek in T4S, R65W as being in the Upper Laramie is incorrect. The Upper Laramie as described by them is part of the Denver Formation, as shown by logs of modern drill holes in which coarse clastics of the Arapahoe Formation intervene between the Laramie Formation and these beds. Also, coal in the Laramie is of subbituminous rank, whereas that in the Denver is lignite.

The most typical rocks of the Denver Formation are dusky-yellow to medium-light-gray claystone, siltstone, and very fine- to fine-grained calcareous sandstone; many of these beds are composed mostly of andesitic sedimentary rocks. Also, carbonaceous shale and lignite beds are present almost everywhere in the formation, but lignites are thin or absent in localities near the mountains. In the city of Denver, Cross found scattered outcrops of the formation, including a thin bed of coal, and just east of Denver along the bank of Sand Creek he found "a continous outcrop of typical Denver beds composed of shales and sandstones, with lignitic seams" (Emmons, Cross, and Eldridge, 1896, p. 193, 194). These lignite-bearing beds are continuous with the lignitic beds farther east, in the Watkins area, and from there southward to and beyond Calhan, a distance of about 130 km north-northwest to south-southeast. From this belt of surface exposures, lignitic and andesitic materials can be traced westward in drill holes below the thick Dawson Arkose to within a short distance of the edge of the Denver basin.

Some conglomerate beds are present, increasing in proportion westward toward the mountains, particularly near Green Mountain, where the formation was first described and where it consists predominantly of andesitic materials. In the Golden-Green Mountain area, basaltic and latitic lava flows are interbedded. Laminae consisting of as much as 50% or more magnetite occur in some sandstone beds in various parts of the basin. Fine- to coarse-grained and conglomeratic arkose beds are present in the formation locally, and these become thicker and more numerous westward toward the mountains.

At what Hares (1926) considered the type locality of the Denver Formation, the western slopes of Green Mountain in T4S, R70W, Smith (1964) measured a thickness of 290 m. From subsurface information in the deeper parts of the Denver basin, the author has found that the formation ranges in thickness from about 300 to 460 m. To the east, however, it becomes thinner owing mostly to pre-Dawson Arkose erosion, and ranges in thickness mostly from about 200 to 275 m in Twps. 6 to 10 S, Rgs 60 and 61 W.

The age of the Denver Formation is Late Cretaceous and Paleocene (Brown, 1943; Smith, 1964). There is apparently no unconformity between the Cretaceous and Paleocene parts of the formation. Except for a few localities such as South Table Mountain, where Roland W. Brown (1943) of the U.S. Geological Survey found Paleocene mammal and plant fossils about 15 m above Cretaceous vertebrate fossils, the Cretaceous-Paleocene boundary cannot be placed with certainty. C.L. Gazin (1941, p. 291) wrote that Brown considered the boundary in the southeast Denver basin to be "near the base of the zone of workable coal,"

that is, the lignite beds just mentioned. Farther north, there are some persistent sandstone beds just below this lignite zone, and perhaps the top of these sandstone beds may approximately mark this time boundary (Soister, 1972b). Studies of pollen samples by R.H. Tschudy of the U.S. Geological Survey show that approximately the upper half of the Denver Formation is of early Paleocene age, and that the uppermost part is possibly of middle Paleocene age (Soister and Tschudy, this volume). All but two pollen samples collected from the upper half of the Denver indicated an age of early Paleocene; the other two samples had pollen specimens that represent Early to Middle Paleocene age. Mammalian fossils found in the formation so far are of Puercan (early Paleocene) age of Wood and others (1942); localities include SW¼NW¼ sec. 31, T3S, R69W at South Table Mountain (Brown, 1943, p. 73-74), sec. 6, T14S, R64W at Corral Bluffs (Brown, 1943, p. 75; Soister, 1968b), and sec. 33, T5S, R68W (Peter Robinson, Univ. of Colorado, oral commun., 1974).

GREEN MOUNTAIN CONGLOMERATE

This formation is recognized by the U.S. Geological Survey only on Green Mountain, in T4S, Rgs 69 and 70 W. Cross originally included it as his division D of the Denver Formation (Cross, 1888; Emmons, Cross, and Eldridge, 1896). It consists of fine to coarse conglomerate (some boulders more than a meter in diameter), and of finer grained rocks. Smith (1964) showed that the Green Mountain Conglomerate is predominantly sandstone, siltstone, and claystone, rather than conglomerate as previously believed. He subdivided it into four lithologic units. Examination of some of the few available outcrops reveals fluviatile sandstone as well as claystone and siltstone beds typical of continental basin deposition and quite similar to beds farther east in the Denver basin.

Reichert (1954, 1956) proposed dropping this formation name because he believed it was actually part of the Dawson Arkose. This author has found that over much of the Denver basin a lenticular unit resembling, and believed to be correlative with, the Green Mountain Conglomerate, forms the basal part, or lower member, of the Dawson Arkose.

Thickness of the Green Mountain Conglomerate is about 600-650 ft (180-200 m). The age of the formation is Paleocene (Smith, 1964; Scott, 1972); no pollen samples have been collected nor studies made in order to more precisely date the formation.

DAWSON ARKOSE

There is no completely exposed surface stratigraphic section of the entire Dawson Arkose, as acknowledged by Richardson (1915, p. 7) when he named this formation while mapping the Castle Rock 30-minute quadrangle. The formation was named from Dawson Butte (sec. 6, T9S, R67W and sec. 1, T9S, R68W), at the west-central edge of the Denver basin.

At Dawson Butte, Richardson included all rocks above the Laramie Formation in the Dawson Arkose. However the lowermost part of this interval is the Arapahoe Formation and an intermediate interval, perhaps 170 m in thickness, is obscured by colluvial and landslide deposits. These beds probably represent the Denver Formation, because a nearby water well penetrated mostly fine-grained rocks which are referred to that formation. There are excellent exposures of the upper 230 m of strata on the butte, in gashes carved by torrential rains during the severe storms and flooding of June 1965; this is the bulk of the Dawson Arkose as exposed over most of the Castle Rock quadrangle mapped by Richardson.

The Dawson can be subdivided into at least a few members, but this author has designated only two. The lower member is best characterized as one of mixed lithology because it contains both andesitic and arkosic materials with grain sizes ranging from clay and silt to cobbles. In some localities, one or two beds of carbonaceous shale or impure lignite are found in the basal part, and some carbonaceous shale lenses locally higher up. In places, particularly in the eastern part of the basin, the member thins to a few meters or is absent. However, the thickness of this lower member is generally in the range of 60-125 m. Pollen samples from beds believed to represent this member were of late Paleocene age (Soister and Tchudy, this volume).

Overlying this lower member of the Dawson is a persistent to intermittent interval of variegated (red, yellow, purple, white) claystones and deeply altered sandstones and conglomerates which represents one or more ancient soil profiles, or paleosol. This paleosol interval, from a few meters to as much as about 20 m thick, is widespread around the north, east, and southeast sides of the basin and is also present locally along the south and west sides. The paleosol has been noted in many drill holes throughout the Denver basin to depths of at least 273 m (Soister and Tschudy, this volume, Fig. 1). In the southeast part of the basin, the paleosol is near the base of the Dawson Arkose because the underlying lower member of the Dawson is thin or absent there. About six thin red claystone beds in the lower exposed part of the Dawson Arkose at Dawson Butte are believed to be equivalents of this paleosol Georgely Markos, of the University of Colorado, has found the bauxite minerals gibbsite and boehmite in samples from the paleosol, and from his preliminary studies believes (oral commun. 1977) that the sequence is a soil, probably composite in some places, that formed under moist tropical or subtropical conditions over long periods of time. The paleosol is believed to have developed in late Paleocene and early Eocene time (Soister and Tschudy, this volume).

Above the paleosol, and in areas where the paleosol is not found, the main body of the Dawson Arkose is composed mostly of arkose and conglomerate with lesser amounts of sandy claystone. What may be considered a typical stratigraphic section of the Dawson Arkose, in the broad plains area of the Denver basin, is one composed of 70-90% white to light gray or pale yellow very coarse-grained arkose and granite granule to pebble conglomerate in beds several to a few tens of meters thick, and the remaining 10-30% composed mostly of green sandy

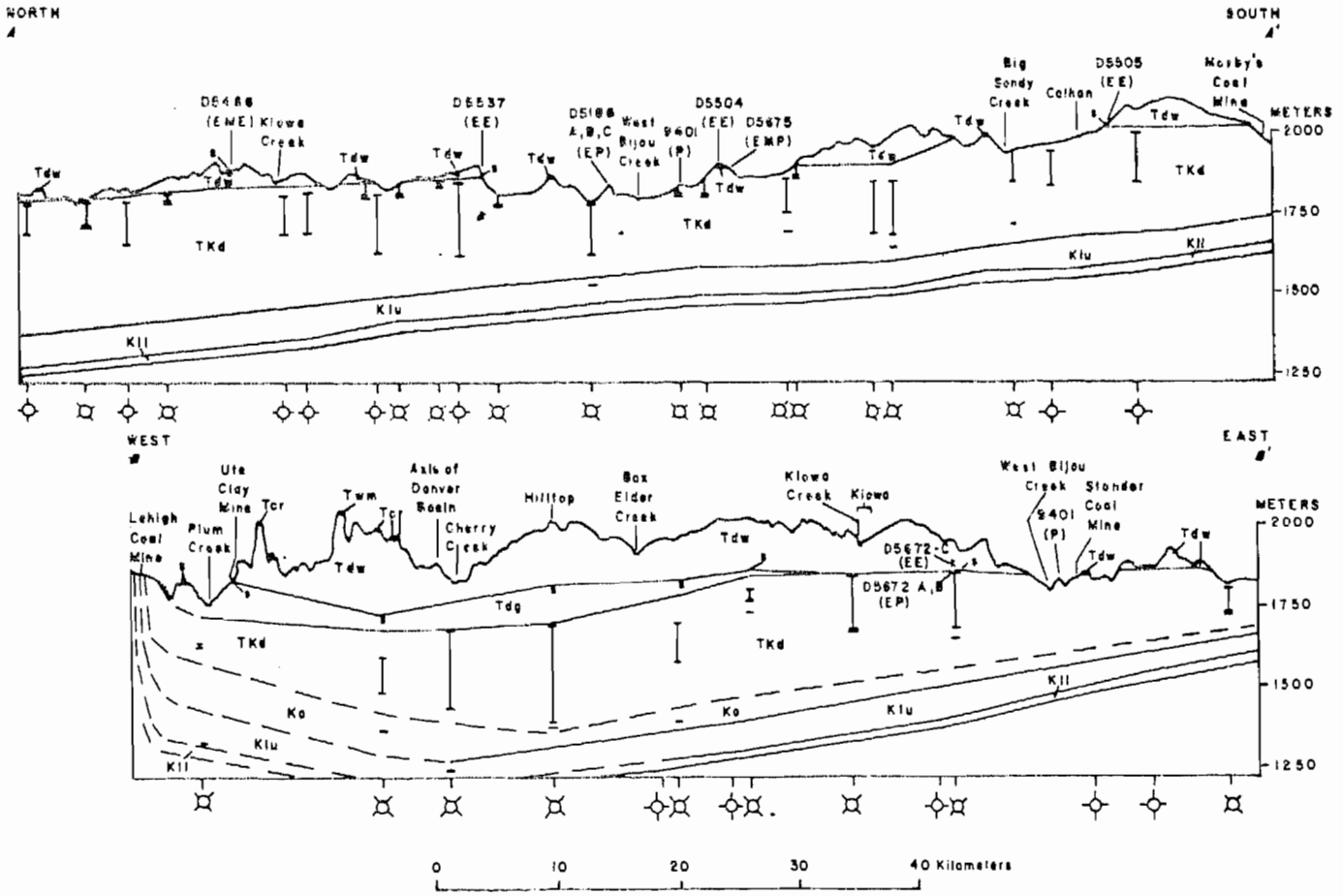

Fig. 3—Stratigraphic cross-sections in the Denver basin, showing formational relationships. Symbols: Kll, lower or sandstone member, and Klu, upper or coal-bearing member, both of Laramie Formation; Ka, Arapahoe Formation; Tkd, Denver Formation; Tdg, lower member, and Tdw, main body, both of Dawson Arkose; Twm, Wall Mountain Tuff; Tcr, Castle Rock Conglomerate; s, paleosol. Fossil localities: D5504, USGS Paleobotany locality number; P, Paleocene flora; EP, early Paleocene pollen; EMP, probable early middle Paleocene pollen; EE, early Eocene pollen; EME, early middle Eocene pollen. Location of drill holes along section shown by tick marks and symbols at bottom: ⌖ oil test holes, used mostly for control on Laramie Formation; ⌑ coal or uranium test holes, or water wells. Vertical lines in Denver Formation show depth range of coal beds found in drill holes; small tick marks below show total depth of holes.

claystone in beds a few meters thick.

In Twps 9 and 10 S, Rgs 66 and 67W, where the formation attains its maximum thickness of about 427 m, the uppermost 30 m or so includes some partly tuffaceous beds and a conspicuous coarse intraformational conglomerate. The main body of the Dawson Arkose is of Eocene age (Soister and Tschudy, this volume), but these uppermost beds have not been dated. The Wall Mountain Tuff and the Castle Rock Conglomerate, both of early Oligocene age, overlie the Dawson in the area of these uppermost beds, and locally overlie the Dawson in other parts of the basin.

RELATIONS OF DENVER FORMATION AND DAWSON ARKOSE

Some authors, working along the west side of the basin and almost exclusively with surface exposures, have been inclined to lump all rocks between the Laramie Formation and the rocks of Oligocene age into a single formation, the Dawson Arkose or Dawson Formation (note Fig. 2). This trend was begun by Richardson (1915, p. 8); in relying on surface exposures, he stated that the Dawson Arkose merged laterally northward with, and could not be differentiated from, the Arapahoe and Denver Formations. However, he also stated (Richardson, 1912, p. 268) that "the Arapahoe and Denver are equivalent to the lower part of the Dawson Arkose . . . " and not to the entire Dawson as some modern authors infer. In another part of that report, however, Richardson (1912, p. 274), in writing of the stratigraphic relations of the Dawson to the Denver and Arapahoe, wrote that they ". . . are generally concealed by a cover of Quaternary deposits, so that actual conditions are obscure. It is not claimed for the recent work that final correlations have been established . . ."

Accepting Richardson's idea that the Arapahoe and Denver could not be differentiated from the Dawson, but also finding that there were two lithologically separable units, Dane and Pierce (1936, p. 1309-1310) mapped all the post-Laramie and pre-Oligocene rocks in the southeast

Denver basin as Dawson Arkose, dividing it into an upper division and a lower division. Some authors have followed this work with the same terms or these of upper Dawson and lower Dawson.

Reichert (1954, 1956), in undertaking the first basinwide study of the rocks of latest Cretaceous and early Tertiary age of the Denver basin, subdivided them into Arapahoe Formation, Denver Formation, and Dawson Arkose. He proposed dropping the terms lower division and upper division of the Dawson of Dane and Pierce (1936) and replacing them with Arapahoe and Denver for the former and Dawson for the latter.

The present author first allowed the common belief that these rocks could not be separated into two or more formations. Thus the term Dawson Formation was used for strata equivalent to both the Arapahoe and Denver Formations that should have been termed Denver Formation in the north, east, and south parts of the Denver basin (Soister, 1965a, 1965b, 1965c, 1968a, 1968b, 1972a). Later, upon studying the lignite and associated beds in the central part of the basin, it was found that the Dawson Arkose unconformably overlies the Denver Formation (Soister, 1972b, 1974). Just south of Denver, Maberry and Lindvall (1974) were also able to distinguish the Denver from the overlying Dawson; this area borders on the north the area mapped by Richardson (1915).

As a result of the lignite studies, the author found an excellent mappable contact, identifiable in the subsurface as well as at the surface, between the Denver Formation and the Dawson Arkose. This contact was adopted by Tweto (1976) for the new state geologic map. These two formations are separable on both lithologic and age bases. The relationship of the Denver and Dawson was studied at the surface, especialy in the area of extensive exposures which extends from T4S, R63W, to T12S, Rgs61-63W. About 24,000 m of drill-hole samples were examined and coordinated with electric logs; about 500 logs of shallow coal exploration drill holes, and some drill cores, were studied; drillers' logs of several hundred water wells were examined. Utilizing these data, seven east-west and two north-south cross sections linking outcrops and drill-holes across the basin have been drawn. These cover distances ranging from about 65 to 116 km. Two of them, greatly reduced, are reproduced here (Fig. 3) to show the relations of these formations.

In addition to illustrating that the relationship of the Dawson Arkose to the Denver Formation is one of superposition, the cross-sections also show that coal beds are present in the Denver over most of the basin. The underlying Arapahoe Formation is not separated from the Denver in one of these cross sections because, especially in the eastern part of the basin, the contact between these two formations is difficult or impossible to determine from drill-hole data.

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